Fluor's Econamine FG Plus^{SM} Technology

An Enhanced Amine-Based CO_2 Capture Process

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The Econamine FG^{SM} and Econamine FG Plus^{SM} technologies are Fluor proprietary amine-based carbon dioxide removal processes. All of the Econamine FG^{SM} and Econamine FG Plus^{SM} technology described in this paper is protected by existing or pending patents owned by Fluor.

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Background: Econamine FG^{SM} Process

The Econamine FG Plus^{SM} technology is an advanced version of Fluor's Econamine FG^{SM} technology, which has been used in 23 commercial plants for the recovery of carbon dioxide from flue gas.

Econamine FG^{SM} technology uses monoethanolamine (MEA) as the basis of its solvent. However, the solvent formulation is specially designed to recover CO_2 from low pressure, oxygen-containing streams, such as burner flue gas streams. Therefore, it is a post-combustion CO_2 capture system and is easy to retrofit to existing facilities. Combined cycle gas turbine and coal-fired power plants are good candidates for this technology. Chemical and fertilizer plants requiring additional CO_2 as a feedstock can also benefit from this technology.

Carbon dioxide capture can be used for the following applications:
- CO_2 sequestration
- Enhanced oil recovery (EOR)
- Merchant CO_2 sales
- Chemical feedstock production

Most alkanolamine systems cannot operate in a flue gas environment, because the amine will rapidly degrade in the presence of oxygen.[1] This is prevented in the Econamine FG^{SM} solvent by the addition of a proprietary inhibitor. This inhibitor also protects the equipment against corrosion and allows for conventional materials of construction, mostly carbon steel.

The Econamine FG^{SM} flowsheet is similar to a generic gas treating process, which has been practiced for many years. All equipment items and operations are simple, reliable, and generally familiar to operating personnel. A typical Econamine FG^{SM} flowsheet is presented in Figure 1, for reference.

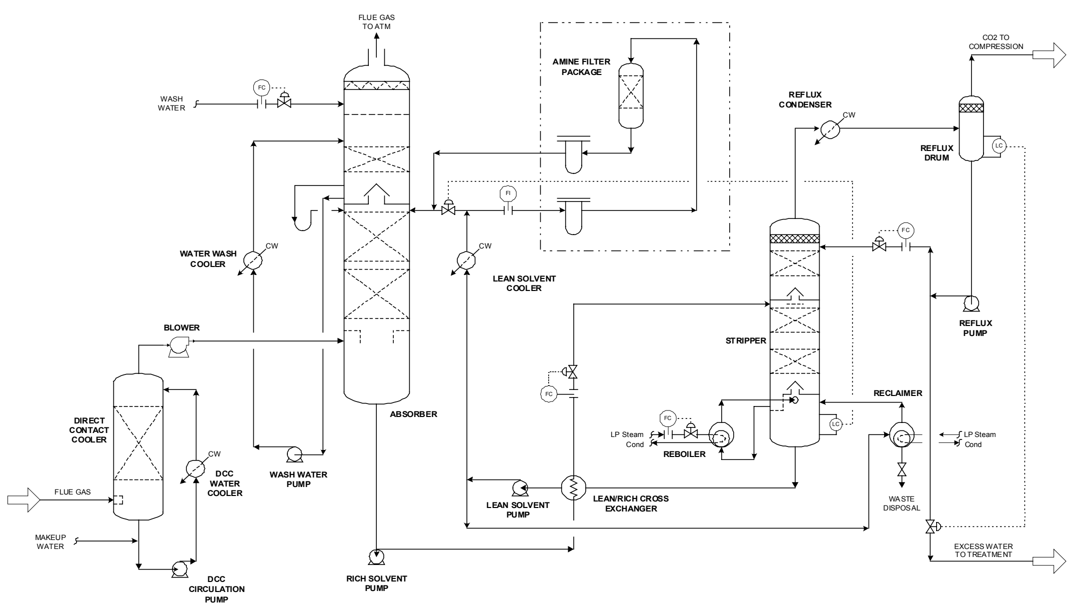

Figure 1: Typical Econamine FG^{SM} Flowsheet

The Econamine FG^{SM} process can treat gas from a pressure sensitive CO_2 emitting source, such as a steam-methane reformer (SMR) flue gas line without any adverse effects. At one facility in the USA, the

Econamine FG^{SM} plant is located on the exhaust duct of a gas turbine in a power plant, where neither a backpressure nor a pressure fluctuation can be tolerated. The technology is also located on reformer flue gas lines in India and Brazil. All of these plants consistently remove the carbon dioxide from the flue gas without disturbing the upstream pressure.

In order to avoid the formation of heat stable salts in the solution, SO_X, NO_X (specifically NO_2 and N_2O_4), and particulates must be reduced to an acceptable level upstream of the Econamine FG^{SM} absorber. This step can be incorporated into Fluor's total project solution for the Econamine FG^{SM} or (Econamine FG Plus^{SM}) CO_2 capture plant.

Commercial Plant Example: FPL Facility at Bellingham, MA

The Econamine FG^{SM} technology has been successfully implemented at 23 commercial plants worldwide. One of these plants is a 360 STPD (327 Te/d) CO_2 recovery plant in the Florida Power and Light power plant in Bellingham, MA, USA. The Econamine FG^{SM} plant was designed and constructed by Fluor, and has been in continuous operation since 1991.

This facility is the only commercial-scale CO_2 recovery unit in the world operating on gas turbine flue gas. This is notable for three reasons:

1. The CO_2 concentration in the flue gas is low, being only 2.8 to 3.1 vol%.

2. The oxygen concentration in the flue gas is high, being approximately 13 vol%.

3. Neither a backpressure nor a pressure fluctuation in the flue gas line can be tolerated.

The quality of the carbon dioxide product is suitable for use in the food and beverage industry. This is a better quality CO_2 than is needed for sequestration EOR.

Figure 2 shows an aerial view of the Bellingham Econamine FG^{SM} plant. The plant design was based on air cooling only, hence the large bank of air coolers. The area shown in the picture also includes the CO_2 liquefaction, storage, and truck loading facilities. Figure 3 shows a ground level view of the absorber and stripper in the Bellingham facility.

Fluor has used the experienced gained at the Bellingham facility to develop expertise on amine degradation and corrosion prevention strategies. In fact, Fluor is the only technology vendor with long term commercial operating experience with CO_2 recovery from flue gas with a very high oxygen concentration. This translates into a more reliable and cost effective design and operation of the Econamine FG Plus^{SM} plant.

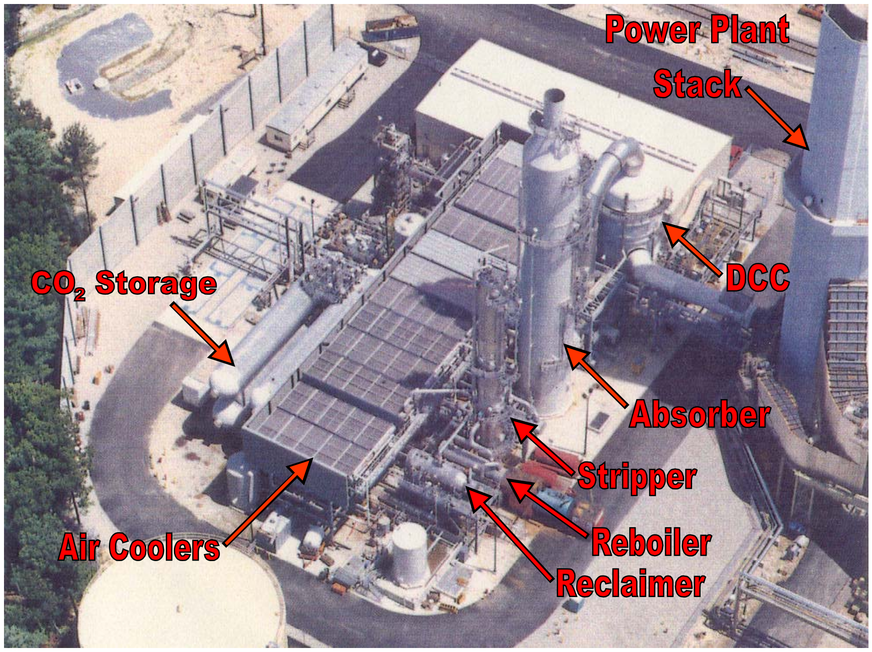

Figure 2: Bellingham Econamine FG℠ Plant Aerial View

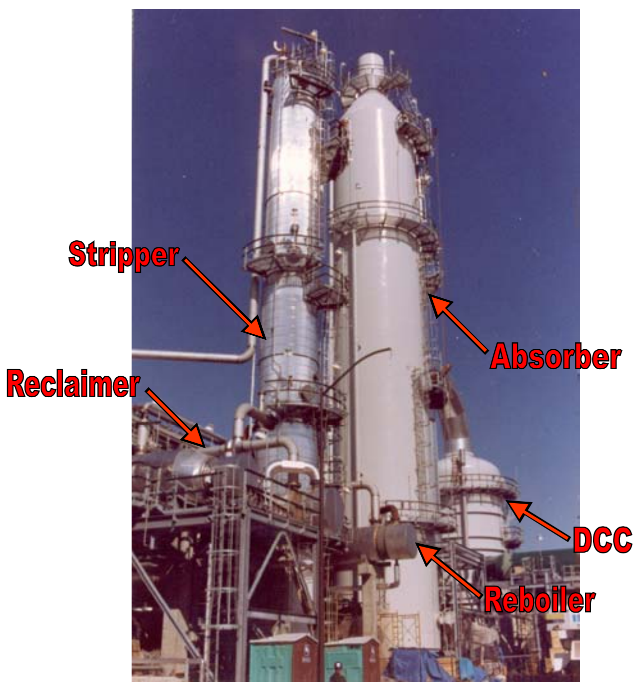

Figure 3: Bellingham Econamine FG℠ Plant Ground View

Future of Carbon Dioxide Recovery Plants

Large-scale carbon dioxide sequestration projects are currently being planned. With absorber diameters of 40 to 50 feet considered feasible (Figure 4), CO_2 recovery plant capacities of up to 8,000 Te/d are achievable, depending on the inlet flue gas CO_2 concentration. Even larger plants can be realized by employing multiple absorbers sharing a common stripper. The Econamine FG℠ (and Econamine FG Plus℠) technology can be applied today to these large-scale CO_2 capture plants.

Figure 4: Fluor's Econamine (DGA) Plant in Uthamaniyah, Saudi Arabia has an absorber (center-right) with a large diameter.

Econamine FG Plus℠ Technology

Using the Econamine FG℠ technology and experience as a starting point, Fluor has developed an improved process called Econamine FG Plus℠. The new technology targets a goal of further lowering the energy consumption of the process. The Econamine FG Plus℠ process is now being commercially offered.

The elements of the Econamine FG Plus℠ technology include the following features:
- Improved solvent formulation
- Split flow configuration
- Stripping with condensate flash steam
- Absorber Intercooling
- Integrated steam generation

The above list serves as a menu of options from which a customized plant design can be developed to satisfy the specific requirements and operating parameters of each CO_2 removal application. In this way, Fluor can develop an optimized solution that minimizes the energy consumption, rather than offering only a standard design that was originally optimized for a different plant with different operating conditions.

<u>Improved Solvent Formulation</u>

An important feature of the Econamine FG Plus℠ process is a new solvent formulation. The predominant amine for the solvent remains MEA, but the new formulation has the following benefits:

- Increased Reaction Rates: This decreases the required packing volume in the absorber, allowing a smaller, less expensive absorber.

- Higher Solvent Capacity for CO_2: Because the solvent is capable of carrying more CO_2, less solvent circulation is required. This includes a decreased solvent flow through the stripper, thereby reducing the reboiler steam requirement.

Of course, the solvent still contains the proprietary inhibitor, and retains the low amine degradation and low corrosion qualities of the original Econamine FG^SM solvent.

Split Flow Configuration

Another feature of the Econamine FG Plus^SM process is a modified split flow configuration. In this configuration, two parallel regeneration schemes are utilized: flash regeneration and steam stripping.

The first portion of the rich solvent is regenerated in the stripper. Steam stripping removes the most carbon dioxide from the solvent and therefore provides the leanest solution, called lean solvent. A reboiler, requiring an external source of heat, provides the necessary energy to the stripper. This portion of solvent regeneration is identical to the standard Econamine FG^SM stripper configuration.

The second portion of rich solvent is preheated against the lean solvent stream and then regenerated by flashing in a flash drum. The flashed solution contains more carbon dioxide than the lean solvent produced in the stripper, and is called semi-lean solvent. However, it is made without any additional steam requirement; the energy required for regeneration is provided by recovering the heat remaining in the lean solvent stream after it leaves the stripper reboiler.

Since some of the solvent entering the absorber has a higher loading with the split flow configuration, a higher circulation rate is required to meet the same recovery specification. However, the steam requirement is decreased because only a portion of the rich stream is being stripped to the leanest solution with external heat. As such, the split flow configuration decreases the energy consumption for the Econamine FG Plus^SM process.

It should be noted that the increase in solvent circulation rate that results from the split flow configuration can be substantially mitigated by the implementation of the other Econamine FG Plus^SM process features. As such, the overall solvent circulation rate of a complete Econamine FG Plus^SM plant is only slightly higher than that of a standard Econamine FG^SM plant.

Stripping with Condensate Flash Steam

This portion of the Econamine FG Plus^SM technology is an extension of the split flow process. In order to decrease the partial pressure of the carbon dioxide above the semi-lean solvent in the flash drum, thereby decreasing the semi-lean solvent loading, steam is added to the flash drum. However, in order to avoid an increase in overall steam consumption, this steam is extracted from the saturated reboiler condensate by flashing it at the semi-lean flash pressure. Hence, no additional steam is required.

The addition of steam to the semi-lean flash drum reduces the semi-lean loading, thereby decreasing the overall solvent circulation rate. The end effect is a decrease in the reboiler energy requirement.

Absorber Intercooling

Absorber intercooling is used to reduce the temperature in the middle of the absorber packed beds, as illustrated in Figure 5.

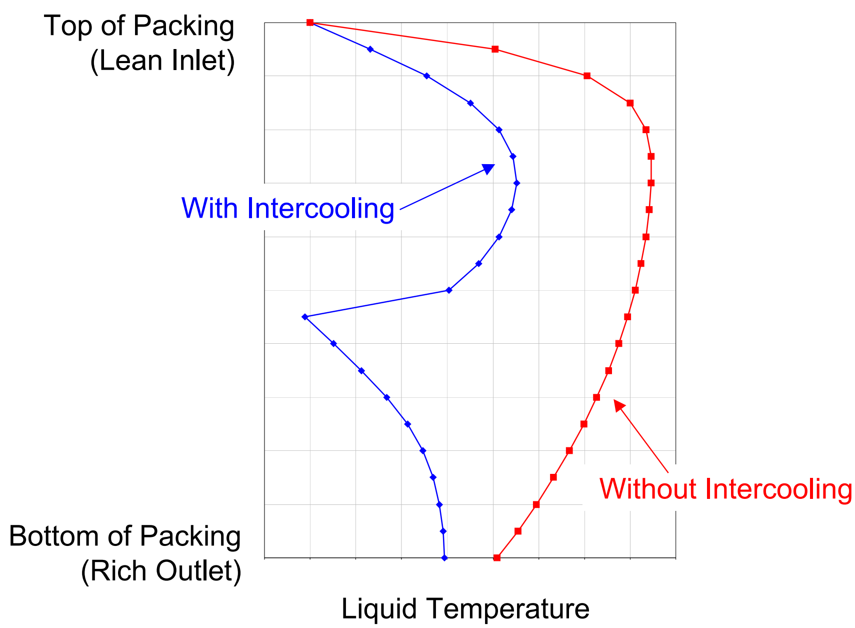

Figure 5: Absorber Temperature Profile with Intercooling

The intercooling has two major effects. First, the overall absorption rate of CO_2 is increased, decreasing the absorber size and capital cost.

Secondly, the rich solvent loading is increased, thereby decreasing the solvent circulation rate. The higher rich loading and the decreased solvent circulation rate both result in a decreased energy requirement in the stripper reboiler.

In a simple two-bed absorber, the cooling is accomplished by extracting the semi-rich solvent from the top (trim) bed of the absorber, cooling this solvent, and returning it to the bottom (bulk) bed of the absorber. If the absorber has more than two beds, then additional intercooling steps can be added.

If the process is a split flow configuration, the semi-rich solvent can be mixed with the semi-lean solvent prior to cooling. Alternatively, only the semi-lean solvent can be cooled without extracting the semi-rich solvent from the absorber. The intercooling philosophy depends on the Econamine FG Plus^SM overall configuration and the specific operating parameters of the plant.

Integrated Steam Generation

Another way the Econamine FG Plus^SM technology can save capital and operating costs is by integrating a steam generation system into the process (Figure 6). All of the Econamine FG Plus^SM steam requirements can be met by such a system. This option is especially attractive when the Econamine FG Plus^SM unit is added to the CO_2 producing plant as a retrofit and a new, dedicated steam generation unit is required.

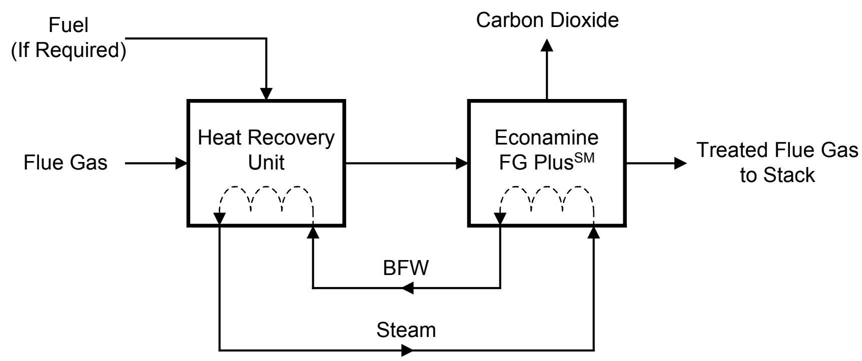

Figure 6: Integrated Steam Generation Econamine FG Plus^SM Plant

There are two primary methods for generating the required steam:

1. If the flue gas temperature is high enough, the steam can be raised from heat recovery alone. Doing so not only generates steam, but it also decreases the load on the direct contact cooler. This scheme is potentially applicable to open cycle gas turbine power plants, furnaces, fired heaters, and any other process that produces a very high temperature flue gas.

2. In some cases, duct firing can be done in the flue gas upstream of the main Econamine FG Plus^SM plant to generate heat, from which steam can be raised. This is done when the flue gas temperature is too low or the flue gas mass flow (i.e. heat flow) is too low to meet the steam requirement.

The duct-firing of the flue gas has the added advantage of increasing the CO_2 concentration in the absorber feed gas, thereby reducing the necessary removal rate of the Econamine FG Plus^SM plant if a fixed quantity of CO_2 recovery is desired. If, instead, the CO_2 emission rate is fixed, then the recovery of the supplemental CO_2 is easier due to the higher gas concentration and the fact that a CO_2 recovery facility is already available on that stream. If the steam were raised in a separate boiler, boiler flue gas ducting and an additional blower would be required to route the flue gas to the Econamine FG Plus^SM unit.

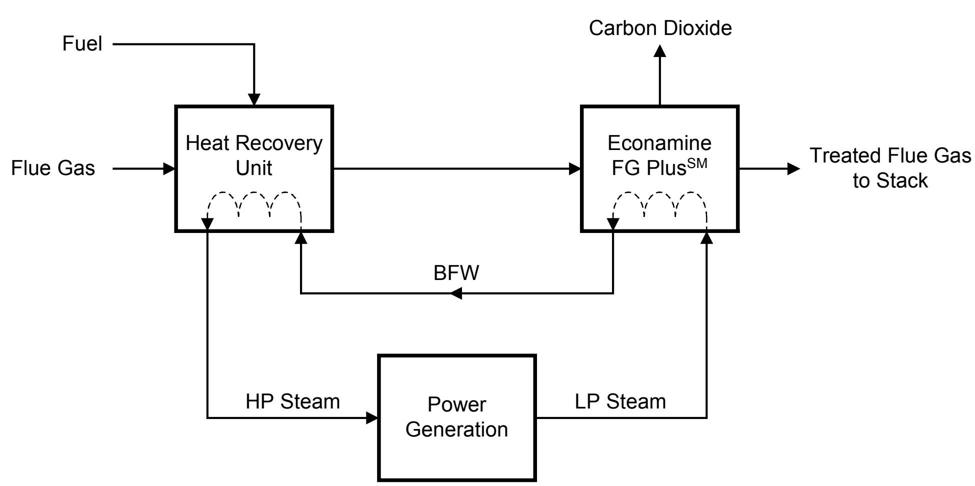

Figure 7: Integrated Steam & Power Generation Econamine FG Plus^SM Plant

Another option is to raise superheated high pressure steam that can first be used for power generation prior to being used as utility steam (Figure 7). This power could be used for the plant's pumps and blower or exported to other parts of the parent facility.

Benefits of Econamine FG Plus^SM Technology

In addition to the added energy savings of the Econamine FG Plus^SM technology, all of the benefits of the original Econamine FG^SM remain. These benefits include:

- Fluor's Econamine FG Plus^SM process is specially designed for removing carbon dioxide from low-pressure, oxygen-containing flue gas streams.

- The plant can be built with conventional materials of construction. The majority of the plant is constructed from carbon steel. Where the potential for corrosion is highest, stainless steel (usually 304SS) is used.

- The Econamine FG Plus^SM technology does not require a custom-manufactured or expensive "boutique" solvent. The MEA solvent is readily available and inexpensive. In fact, it is the lowest cost amine available. MEA is produced by solvent manufacturers worldwide.

- The Econamine FG Plus^SM process has the lowest heat requirement and the lowest solvent circulation rate (for a given configuration) versus all competing MEA-based processes.

- The Econamine FG^SM technology has been successfully demonstrated in commercial applications with more than 20 plants licensed over the past 20 years. In this time, Fluor has further improved the process configuration to lower the energy consumption.

Heat Integration with the Carbon Dioxide Producing Process

Another method of achieving substantial energy savings is by comprehensive heat integration with the process that is producing the CO_2. In this way, heat can be exchanged between process streams, thereby reducing the utility cooling water and steam demands.

Heat integration with power plants and refinery or petrochemical processing plants is feasible. In particular, heat integration with a power plant shows a good synergy. The Econamine FG Plus^SM process-cooling can be accomplished by using vacuum condensate as the cooling source. In this way, the cooling water or air cooling load is minimized, and the heat is productively recovered by the vacuum condensate instead of wasted to a utility stream. Examples of suitable process coolers include the stripper overhead condenser, lean amine cooler, and semi-lean amine cooler.

Comparison of Econamine FG Plus^SM Technology with Other Amine Scrubbing Options

The Econamine FG^SM technology has been successfully demonstrated in over 20 commercial plants, including:

- The only CO_2 absorption plant anywhere in the world that recovers CO_2 at a commercial-scale from gas turbine flue gas

- A 1,000 Te/d (1,100 STPD) CO_2 recovery plant (for EOR)

ABB Lummus Crest, using Kerr McGee Technology, has three commercial plants using and MEA based solvent.[2] However, its solvent strength is low compared to the Econamine FG Plus^SM solvent strength. Because of this, the ABB Lummus Crest plants require both a higher circulation rate and higher reboiler duty than the base Econamine FG^SM process and much more than the Econamine FG Plus^SM process.

MHI/KEPCO have developed a process that uses a proprietary hindered amine known as KS-1. Only one commercial plant has been built.[3] The solvent cost is approximately 5 times the cost of MEA[4,5] (nearly 4.5 times the cost of Econamine FG Plus^SM solvent). Although MHI claims that its solvent losses are much less than those of Econamine FG Plus^SM, the annual cost of solvent replacement is approximately the same.

Case Study: Performance of Econamine FG Plus^SM on Steam Reformer Flue Gas

The performance of the Econamine FG Plus^SM process was investigated on a typical steam reformer flue gas in order to demonstrate the new technology. The flue gas conditions are listed in Table 1.

Table 1: Typical Reformer Flue Gas Conditions

Flow Rate	50,000 Nm^3/h
Temperature	170 °C
Composition	
N_2	68.0 % (v/v)
CO_2	8.0 % (v/v)
O_2	0.9 % (v/v)
Ar	1.00 % (v/v)
H_2O	22.1 % (v/v)
SO_X	2.0 ppmv
NO_X	150 ppmv

The plant recovers 90% of the carbon dioxide for a total product rate of 170 Te/d. The product has a dry purity of over 99.9 vol% CO_2 and its pressure is 0.55 bar-g.

Table 2 shows the energy consumption and amine cost for the process.

Table 2: Econamine FG Plus^SM Energy and Amine Consumption

Energy Consumption	Btu/lb CO_2	1395
Solvent Replacement Cost	US$/Te CO_2	2.30

As seen in the table, the Econamine FG Plus^SM technology exhibits considerably low energy consumption for a CO_2 recovery process. In fact, the energy requirement has decreased by over 20% of the original Econamine FG^SM energy consumption.

These results and the experience of twenty years of operation and 23 commercial plants make the Econamine FG Plus^{SM} process a world-class solution for carbon dioxide recovery.

Summary

The Econamine FG Plus^{SM} process is an efficient, cost effective, and simple process for the removal of CO_2 from low-pressure, oxygen-containing flue gas streams. In developing the technology, Fluor has reduced the energy consumption below that of the original Econamine FG^{SM} process, which was already the most efficient MEA-based process available. The Econamine FG Plus^{SM} technology consists of several process features that can be assembled in many different combinations in order to provide a custom-fit solution to each carbon dioxide recovery application. When combined with heat integration with the parent CO_2 producing plant, additional substantial energy savings can be realized.

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